PIEZOELECTRIC DATA ENTRY DEVICES

FIELD OF THE INVENTION

The invention relates to the field of electronic marking and erasing devices. More particularly, the invention relates to electronic marking and erasing devices having piezoelectric transducers.

BACKGROUND OF THE INVENTION

Electromechanical transducers are used for a variety of applications, including data entry applications such as digitizing pen-and-tablet systems. Data entry systems typically include a writing area, such as a tablet or white board, a position indicating pen, and associated electronics for determining the interaction between the position-indicating pen and the writing area. A digital data entry signal is typically derived to represent the relative position of the position-indicating pen and the tablet.

Ultrasound-based electronic tablets and whiteboards are based on either through-the-air transmission (air transmission) or through-the-surface-of-the-board (solid transmission) of ultrasonic pulses. The position of a movable data-entry device on the writing surface is calculated, typically by the geometric intersection of travel times of ultrasonic pulses measured between the data-entry device and a plurality of fixed-location sensor stations, which are located on the periphery of the writing area. Full coverage of a writing area, such as a tablet or a whiteboard, typically requires a minimum of two fixed-location sensors, and one movable sensor for geometric triangulation.

The actual number of required sensors depends on the radiation angle of the ultrasound transmitter or transmitters (the transmission directivity), the strength of the transmitted signal, the acceptance angle of the ultrasound receivers (the reception directivity), the sensitivity of the receivers to the vibrational frequency of the transmitted pulses, and the accuracy of measuring the travel time of the ultrasonic pulse.

Many prior art tablets or writing surfaces which use pen shaped data-entry devices are based on touch-panel technologies. Typically, complicated grid layers extend across the surface of a tablet, and are held apart by tension underneath the writing surface. The location of a data-entry device, such as a data-entry pen, is determined by the location at which the pen presses the grid layers together. The IBID™ whiteboard from Microtouch, of Methuen, Massachusetts, the SMARTBOARD™ from Microfield Graphics, of Calgary, Alberta, Canada, and various pen-based digitizing tablets from Wacom Co, Ltd., of Saitama, Japan are examples of touch-panel technology electronic whiteboards.

An inherent drawback of prior art touch-panel tablets and whiteboards is that the writing surface is an integral component of the system. As the size of the writing area increases, their portability, ease of installation, and product cost become increasingly problematic.

S. Sindeband, and T. Stone, *Position Determining Apparatus*, U.S. Patent No. 5,379,269 (03 January 1995) disclose an apparatus for determining the position of a movable element over a surface of a solid medium. Sindeband et al. describe an electronic whiteboard system which uses ultrasound to determine the position of a pen-shaped stylus on a writing surface. While Sindeband et al. disclose a movable transmitter, the transmitted ultrasonic energy is required to travel through a solid medium. To obtain a consistent signal through a solid medium, therefore, the transmission characteristics of the solid surface must be uniform.

The establishment of a large homogenous writing structure can be difficult and expensive, and precludes the use of the transmitter pen on a generic surface, such as a white board. Standard white boards are not homogenous structures, typically having a common particle board or MASONITE™ composite backing, with an applied top surface that typically has non-uniform surface characteristics.

Therefore, an electronic whiteboard based on the principles of operation disclosed by Sindeband et al. would require that a special whiteboard writing surface be included in the product cost. As well, Sindeband et al. disclose a

tethered movable stylus, wherein a transmitter is acoustically coupled to the solid medium, which precludes a writing tip within the stylus.

Despite these drawbacks, prior art grid-based tablets and whiteboards typically include data-entry devices which have the look and feel of a pen, and they are designed to be gripped and used like a pen. The user is not required to orient the data-entry device in any special manner.

Ultrasound-based electronic whiteboards that rely on through-the-air transmission of ultrasound pulses, rather than transmission through the solid medium of the whiteboard, offer the opportunity for a product which excludes a dedicated whiteboard writing surface. As an example of such an implementation, an ultrasound transmitter can be located in the movable, pen-style data-entry device. A fixed-position array of ultrasound receivers is located along the periphery of the writing surface. These sensors are used to triangulate the position of the data-entry device on the surface of the whiteboard. The receivers are typically attached directly to a whiteboard, or are mounted to a frame, which is then attached to a whiteboard or other approximately flat writing surface.

Optimally, a sensor for a pen-shaped data-entry device has a transmission directivity that is omni-directional from the writing tip, thus providing cylindrical symmetry to the transmitted signal, which allows the user to hold the device as any pen would be held, without the need to orient a transmitting sensor located on the data-entry device toward other receiving sensors located at the periphery of the writing surface.

In the past, most working examples of omnidirectional ultrasonic transmitters were based on spark-gap designs. L. Roberts, "*The Lincoln Wand*", MIT Lincoln Lab Report, Lexington Mass., June 1966, and P. De Bruyne, "*Compact Large-Area Graphic Digitizer for Personal Computers*", Dec. 1986, pp 49-53, IEEE, disclose examples of spark-gap data-entry devices for electronic whiteboards.

One significant drawback of spark-gap transmitters is the audible, repeated "snap" sound associated with the generation of ultrasound pulses. Another significant drawback with spark-gap transmitters is high power consumption, which

makes untethered battery-powered operation impractical, since batteries must be changed or recharged on a frequent basis.

As well, spark gap transmitters typically have a transmitter tip that resides on the entire pointing tip of the movable device. The mechanism for producing a spark gap signal has to act as a point source, requiring that the end of the transmitter pen is used as an acoustic horn. This hardware configuration prevents the use of a writing tip, such as a standard writing implement or pen cartridge, from being placed within the device, with a writing tip extending from the pointing tip of the device, as such that a user can write upon a surface, such as a white board, while simultaneously sending a position signal from the pointing tip to external receivers.

R. Herrington and K. Burgess, *Wireless Cursor Control System*, U.S. Patent No. 4,654,648 (31 March 1987) disclose a "wireless movable steering means which emits acoustic signals". While Herrington et al. disclose a movable transmitter stylus, the spark gap mechanism inherently precludes the use of a writing pen within the pointing tip of the hand-held stylus.

Similarly, A. Whetstone, S. Fine, W. Banks, and S. Phillips, *Graphical Data Device*, U.S. Patent No. 3,838,212 (03 January 1995) disclose a graphical data device employing a stylus moving over an area to be digitized and utilizing a fast rise time sound energy shock, generated by a spark at the location of the stylus and propagated though the air.

R. Davis and J. Howells, *Position Determining Apparatus and Transducer Therefor*, U.S. Patent No. 4,012,588 (15 March 1977) disclose an apparatus for determining the position of a movable element, wherein "each receiver comprises a hollow shell of piezoelectric material, which may be cylindrical or spherical in shape, and resilient conductive means coupled across the inner and outer surface of the shell". While Davis et al. disclose a cylindrical symmetry for a complicated, stationary, piezoelectric receiver, they fail to disclose the use of a piezoelectric transmitter having cylindrical symmetry within a movable data entry device. In addition, the inner volume of the disclosed cylindrical receiver is filled with a complicated, conductive resilient filling.

S. Mallicoat, *Code-Based Electromagnetic-Field-Responsive Graphic Data-Acquisition System*, U.S. Patent No. 5,248,856 (28 September 1993) discloses an "electromagnetic-field-responsive, code-based, graphic data acquisition system for tracking the operational status of a mobile write-effective component in relation to a defined writing-surface area". While Mallicoat discloses a pen within the data-acquisition system, the pen includes retro-reflecting regions interspersed with substantially non-retroreflecting regions, dispersed circumferentially around the pen, whereby the retro-reflecting regions optically intersect a scanning zone, and reflect light from a scanning light beam source towards a monitoring structure.

M. Biggs, T. O'Ishi, and M. Knighton, *Ultrasonic Pen-Type Data Input Device*, U.S. Patent No. 5,308,936 (03 May 1994) disclose a movable transmitter pointer which simultaneously emits magnetic pulses and ultrasonic pulses. While Biggs et al. disclose an ultrasonic transducer within a movable pointer, the transducer is comprised of a "piezo stack", which is coupled to a complex aluminum diaphragm and a brass reaction mass, which occupies the entire pointing tip of the movable transmitter pointer. The disclosed stylus therefore has an inherent disadvantage of spark gap pointer designs, in that the hardware occupies a large volume of the pointer, and precludes the use of a writing tip within the pointer.

P. De Bruyne, *Apparatus for Determining the Position of a Movable Object*, U.S. Patent No. 4,758,691 (19 July 1988) discloses an apparatus which contains "two fixed ultrasound transmitters, an ultrasound receiver forming part of a movable object, and a calculator". De Bruyne discloses a movable ultrasound receiver transducer which consists of a cylindrical condenser having an air gap with one solid and one movable electrode. The disclosed copper foil electrode does not cover the whole circumference of the cylindrical condenser, and results in an effective range of about 210 degrees.

I. Gilchrist, *Acoustic Digitizing System*, U.S. Patent No. 4,991,148 (05 February 1991) discloses an acoustic sensing apparatus which contains "an acoustic point source transmission device mounted on an indicator for transmitting a sequence of

periodic acoustic oscillations". The disclosed acoustic point source can be configured as a linear stylus, which includes at least a pair of directional acoustic transmitters located away from the pointing tip of the stylus. For two-dimensional position detection, the apparatus employs "at least three acoustic receivers arranged in a non-linear fashion".

M. Stefik and C Heater, *Ultrasound Position Input Device*, U.S. Patent No. 4,814,552 (21 March 1989) discloses an "input device, or stylus, for entering hand drawn forms into a computer using a writing instrument, a pressure switch for determining whether the instrument is in contact with the writing surface, an acoustic transmitter for triangulating the position of the stylus on the surface, and a wireless transmitter for transmitting data and timing information to the computer. In operation, the stylus transmits an infrared signal which the system receives immediately, and an ultrasound pulse which two microphones receive after a delay which is a function of the speed of sound and the distance of the stylus from the microphone". While Stefik et al. discloses a stylus having a cylindrical enclosure that contains a felt tip marker, and an ultrasonic transducer located near the marker tip, the disclosed transducer is a directional, can-style transmitter, such as Part No. 40S2 from Murata, Inc., which has a directivity of not more than 120 degrees. The limited directivity requires that the user must consistently orient the stylus towards the fixed-position receivers located at the periphery of the writing surface, such that the receivers are spaced closely enough such that at least two receivers are always within the 120 degree transmission zone for triangulation of the position of the stylus. If the transmitter stylus is positioned close to any receiver, such as occurs when the receivers are located along the periphery of a whiteboard writing surface, the limited directivity requires a large number of receivers.

J. Romein, *Acoustic Writing Combination, Comprising a Stylus With a Writing Tablet*, U.S. Patent No. 4,246,439 (20 January 1981) discloses an acoustic writing combination which contains a stylus which is "provided with two ultrasonic sources" which emit pulse-shaped sound signals. The disclosed sound sources are point shaped or circular shaped, which may comprise piezo-electric ceramic rings. While Romein discloses the use of cylindrical piezo-electric rings, the stylus

requires two rings to properly locate the pointing tip of the stylus, and does not include a writing tip at the pointing tip of the stylus.

R. Milner, *Acoustic Sonic Positioning Device*, U.S. Patent No. 4,862,152 (29 August 1989) discloses a three-dimensional position control device suitable for controlling computer displays or robot movements, wherein "signals from an ultrasonic transmitter are received by multiple receivers".

R. Garwin, J. Levine, and M. Schappert, *Acoustic Contact Sensor for Handwritten Computer Input*, U.S. Patent No. 4,845,684 (04 July 1989) discloses an acoustic contact sensor for handwritten input, which includes an ultrasonic sending transducer means.

M. Zuta, *Ultrasonic Digitizer Pen Having Integrated Ultrasonic Transmitter and Receiver*, U.S. Patent No. 5,239,139 (24 August 1993) discloses an ultrasonic digitizer pen which includes an ultrasonic transmitter "to transmit ultrasonic waves through the air, to illuminate a writing surface". While Zuta discloses discrete piezoelectric layers, the transmitted signal cones from each of the segments do not overlap.

Small, directional ultrasound transducers are manufactured commercially, such as part number MA40A3, manufactured by Murata Manufacturing Co. Ltd., Kyoto, Japan. Such transducers house a small, thin disc of piezoelectric ceramic material, and are limited to a transmission angle of between 100 and 120 degrees. To achieve a 360-degree ultrasound transmission pattern, a minimum of three to four transducers must be mounted surrounding the tip of the data-entry device. However, each transducer is 1 centimeter in diameter and approximately 1 centimeter in length. Four such devices, when mounted to surround the tip of a pen, must be protected from obstruction by fingers and or other objects that block the ultrasound path between the transmitter and receiver sensors. This may be an impractical, bulky data-entry device.

The disclosed prior art transducers thus provide basic transmission signals for a movable device, but fail to provide a transducer that can transmit an output signal in a radial manner, such as outwardly from the tip of a data entry pen, which can

be received by remote receivers along the periphery of a writing area, such as a white board, while providing access for a writing implement. As well, the disclosed prior art transducers fail to provide a transducer which can transmit an output signal to one or more remote receivers when the transmitter and pen are inclined relative to a writing area. Furthermore, the disclosed omnidirectional prior art transducers fail to demonstrate that the power requirement is low enough to enable wireless, battery powered operation of a data entry device, such as a transmitter pen. The development of such a piezoelectric transducer would constitute a major technological advance.

It would be advantageous to provide a transmitter adapted to a movable transmitter pen which allows a user to use the transmitter pen as a standard white board pen, the way a pen normally would be used, wherein the user can write upon a writing surface at any angle of pen inclination, and without the necessity to orient the transmitter in the pen toward the receivers located along the periphery of the writing surface, while a transmitted signal between the transmitter pen and external receivers simultaneously provides full capture of everything that is written upon the writing surface.

SUMMARY OF THE INVENTION

A piezoelectric transducer is provided, in which a piezoelectric cylindrical shell has conductive layers on the outside and inside of the shell, which are adapted to be connected to a signal input source. When the conductive layers are activated by the signal input source, the piezoelectric layer resonates to produce an output signal waveform, typically having a characteristic sound pressure level, from the shell structure. Alternative embodiments include a flat piezoelectric layer with opposing conductive layers, which is then formed into a shell structure. In a preferred embodiment, an inner spool is located within the shell structure, which supports and maintains the circular cross-sectional profile of the piezoelectric cylindrical transducer, to insure radial transmission of the output signal. To increase the sound pressure level, the inner spool preferably includes a recessed area, which defines a void between the inner conductive layer on the shell and the recessed area. The void acts to maximize the characteristic output sound pressure level for the transducer by allowing the transducer to vibrate freely. In

marking and erasing implement embodiments, one or more piezoelectric transducers are located on a data entry device, and are either used alone, or in conjunction with second output transmitters, such as infrared transmitters, to transmit repeated signals from the data entry device to a receiver, which can be used to accurately determine the location of the pointing tip of the data entry device, in relation to an electronic tablet or white board.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of a radially transmitting or receiving cylindrical shell piezoelectric transducer;

Figure 2 is a detailed top view of a cylindrical piezoelectric transducer, which shows an output signal transmitted from the transducer when the conductive electrode layers are activated by an input signal;

Figure 3 is a detailed side view of a piezoelectric transducer, which shows an output signal to be transmitted from the transducer when the conductive layers are activated by an input signal;

Figure 4 is a cross-sectional view of a cylindrical shell piezoelectric transducer;

Figure 5 is a side view of a transmitter pen having a piezoelectric transducer contained near the writing tip of the pen;

Figure 6 is a partial cutaway view of a transmitter pen having a piezoelectric transducer contained near the writing tip of the pen;

Figure 7 is a partial perspective view of a transmitter stylus having a piezoelectric transducer contained at the pointing tip of the stylus and surrounded by a finger guard;

Figure 8 is a front view of a flexible circuit assembly which can be used in a preferred embodiment of the transmitter pen;

Figure 9 is a partial cutaway view of a preferred transmitter pen, which includes a flexible circuit assembly and a pressure-sensitive activation switch;

Figure 10 is a partial cutaway view of a dual-signal transmitter pen having a first output signal transducer and a second output signal transducer;

Figure 11 is a detailed cutaway view of the pointing tip of a dual-signal transmitter pen having a first output signal transducer and a second output signal transducer;

Figure 12 is a partial perspective view of the pointing tip of a dual-signal transmitter stylus having a plurality of first output signal transducers and a single second output signal transducer;

Figure 13 is schematic view of the transmission of first output signal and a second output signal from a dual-signal transmitter pen;

Figure 14 shows a short pulse waveform of a typical second output signal sent from a dual-signal data entry device;

Figure 15 shows a shaped pulse waveform of one embodiment of a first output signal sent from a dual-signal data entry device;

Figure 16 is a partial cross-sectional view of an alternate embodiment of a piezoelectric transducer and an inner spool;

Figure 17 is a partial cross-sectional view of an alternate embodiment of a piezoelectric transducer and an inner spool having a back air cavity;

Figure 18 is a graph of the output sound pressure level from a piezoelectric transducer;

Figure 19 is a graph of the output sound pressure level from a piezoelectric transducer with air-back cavity on an inner spool;

Figure 20 is a front view of a flat piezoelectric assembly having opposing conductive layers and lead attachment extension tabs;

Figure 21 is a side view of a flat piezoelectric assembly having opposing conductive layers and lead attachment extension tabs;

Figure 22 is a perspective view of a piezoelectric transducer shell formed from a flat piezoelectric assembly;

Figure 23 is a perspective view of a piezoelectric transmitter pen inclined against a writing surface;

Figure 24 is a partial detailed side view of a piezoelectric transmitter pen inclined against a writing surface;

Figure 25 is a front view of a piezoelectric data entry device being used against the writing surface of a white board;

Figure 26 is a top view of a piezoelectric transmitter mouse;

Figure 27 is a cross-sectional view of a multiple-element output cylindrical piezoelectric transducer, wherein the element shape is determined by the pattern of the electrodes on the piezoelectric substrate;

Figure 28 is a front view of a multiple-element output planar piezoelectric transducer, wherein the element shape is determined by the pattern of the electrodes on the piezoelectric substrate;

Figure 29 is a cross-sectional view of segmented piezoelectric transducer elements within an insulative substrate shown in a planar assembly;

Figure 30 is a cross-sectional view of segmented piezoelectric transducers within an insulative substrate shown in a cylindrical assembly;

Figure 31 is a cross-sectional view of segmented piezoelectric transducer elements within a conductive substrate;

Figure 32 is a cross-sectional view of segmented piezoelectric transducer elements located on an insulative planar substrate;

Figure 33 is a cross-sectional view of segmented piezoelectric transducers elements located on an insulative cylindrical substrate;

Figure 34 is a cross-sectional view of segmented piezoelectric transducer elements located on a conductive planar substrate;

Figure 35 is a partial cutaway view of a planar composite comprising separated piezoelectric segments;

Figure 36 is a partial cutaway view of an alternate composite structure comprising separated piezoelectric segments, which are separated by an intermediate material;

Figure 37 is a cross-sectional view of a composite segmented piezoelectric transducer;

Figure 38 shows an alternate shell piezoelectric transducer formed from a continuous thick-walled tube of piezoelectric material;

Figure 39 shows a poling process for use during the production of an extruded thick-walled tube of piezoelectric material;

Figure 40 is a partial side view of a preferred embodiment of a transmitter pen which includes two opposing clam-shell connectable housing halves;

Figure 41 is a partial end assembly view of a clam-shell transmitter pen;

Figure 42 shows an end view of an alternate embodiment of a dual-signal electronic data entry device, having a plurality of infrared transmitters, as well as a plurality of piezoelectric ceramic transmitters;

Figure 43 shows an end view of an alternate embodiment of a single signal electronic data entry device, having a plurality of piezoelectric ceramic crystalline transmitters;

Figure 44 is a partial cross-sectional view of a single-signal erasing implement;

Figure 45 is a partial cross-sectional view of a dual-signal erasing implement;

Figure 46 is a top view of a defined path of a piezoelectric erasing implement on a white board system; and

Figure 47 shows a preferred embodiment of a combined piezoelectric marking and erasing implement.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 is a perspective view of a piezoelectric transducer 10. A piezoelectric layer 12, typically having a cylindrical shape 14, has an outer conductive layer 16a and an inner conductive layer 16b. The outer conductive layer 16a and outer conductive layer 16b are electrodes, which typically are physically or chemical deposited onto the piezoelectric layer 12. In a preferred embodiment, the piezoelectric layer 12 is composed of polyvinylidene difluoride (PVDF), or of copolymers of PVDF. PVDF film is presently available from manufacturers such as Measurement Specialties, Inc., of Fairfield, New Jersey, and Ktech Corp., of Albuquerque, New Mexico. PVDF film is typically easy to cut and shape, and is relatively unbreakable. As well, PVDF is readily bonded to other materials or to itself.

In an alternate embodiment, piezoelectric ceramic may be custom-fabricated in the form of a cylindrical-shell transducer 10 that can surround the tip of a marker

pen 34 (FIGS. 5,6). Fabricated piezoelectric ceramic elements are presently available through, for example, Murata Manufacturing Co. Ltd., or the Piezoelectronics Division of Motorola, Inc., of Albuquerque, New Mexico. However, cylindrically shaped, bare piezoelectric ceramic elements 12 are typically expensive to manufacture, and are brittle and fragile. Therefore, cylindrically shaped, bare piezoelectric ceramic elements 12 are difficult to use in a hand-held data entry device.

As shown in Figure 1, a first signal lead 18a is attached to the outer conductive layer 16a by lead connection 19a, and a second signal lead 18b is attached to the inner conductive layer 16b by lead connection 19b. The lead connections 19a and 19b are typically achieved either by conductive polymers, ultrasonic welds, low temperature solder, heat stakes, rivets, brads, or eyelets.

The signal leads 18a, 18b are adapted to be connected to a signal input source 22a, as shown in Figure 2. When the conductive layers 16a, 16b are activated by an applied voltage 21 from the signal input source 22a, the piezoelectric layer resonates to produce an output signal waveform 24 (FIG. 3), typically having a characteristic sound pressure level 86 (FIGS. 18,19), from the shell structure 10.

Outer protective coatings 93a,93b (FIG. 21), such as thin coatings of a polymer or resin, are preferably used to protect the conductive layers 16, to prevent abrasion, tarnishing or discoloration of the conductive layers 16. However, for many embodiments, the application of protective coatings 93a,93b is expensive, and the combined thickness of the electrode 16 and protective coating 93a,93b may be hard to control, which can produce undesirable variation in the resonant frequency or sound pressure level output of the piezoelectric layer 12.

In some preferred embodiments, the electrically conductive surface layers 16 are made of materials having high electrical conductivity, such as silver, silver-based compounds or alloys, gold, or gold-based compounds or alloys. The preferred conductive layer electrodes 16a, 16b comprise a mixture of carbon and silver, which eliminates visible tarnishing or discoloration. The preferred methods of forming the conductive electrode layers 16 are by silk screen or by vacuum

deposition processes. When used with a finger guard 38 (FIGS. 5-7, 10-12), the use of the preferred carbon-silver layer 16 reduces the manufacturing costs for the piezoelectric transducer 10, and provides better control of the finished thickness, thereby reducing variation in the resonant frequency of the piezoelectric transducer 10.

Figure 2 is a detailed top view 20 of the cylindrical piezoelectric transducer 10 shown in Figure 1. An output signal 24 is transmitted from the transducer 10 when the conductive layers 16a, 16b are activated by an input signal 21 from a signal input source 22a through signal leads 18a, 18b. The generally cylindrical shape 14 of the piezoelectric transducer 10 allows the output signal 24 to be transmitted radially outward from the piezoelectric transducer 10, so that the output signal 24 can be received at a number of remote receivers 110 (FIG. 23).

Figure 3 is a detailed side view of the piezoelectric transducer 10, which shows an output signal 24 transmitted from the transducer 10 when the conductive layers 16a, 16b are activated by an input signal 21. In addition to the radial nature of the output signal 24 from the piezoelectric transducer 10, the output signal 24 waveform typically spans a transmission angle 26 across the length of the piezoelectric transducer 10, providing significant vertical broadening of the transmission directivity. The vertical directivity angle 26 becomes larger as the height of the cylinder 12 becomes smaller.

Figure 4 is a cross-sectional view of a basic cylindrical piezoelectric transducer 10, having a conductive outer layer 16a and a conductive inner layer 16b on a piezoelectric film 12. The thickness of the piezoelectric polymer film 12 effects the sound pressure level (SPL) output 86 of the piezoelectric transducer 10. While the piezoelectric transducer 10 shown is substantially cylindrical, other embodiments are also possible, such as generally oval or polygonal transducers 10.

Single Signal Transmitter Pen and Stylus. Figure 5 is a side view of a transmitter pen 30, which is used as a data entry device. The transmitter pen 30 has a piezoelectric transducer 10 contained near the writing tip 36, as shown in the partial cutaway view in Figure 6. A writing pen 34 is located within the shell

structure of the transmitter pen 30, and has a writing tip 36 that extends though one end of the shell 32. The writing tip 36 typically extends through the hollow central area defined by the piezoelectric transducer 10. A signal input source 22a is located within the shell, and is electrically connected to the piezoelectric transducer 10 by signal leads 18a and 18b. Signal leads 18a,18b and lead connections 19a,19b between the power source circuit 22a and the piezoelectric transducer 10 are established, either before or after the piezoelectric transducer 10 is placed into the shell 32.

In a preferred embodiment, a finger guard 38 surrounds the piezoelectric transducer 10. The finger guard 38 protects the piezoelectric transducer 10 from mechanical damage, and confines the angle 106 of the pen 30 against writing surfaces (FIGS. 23, 24) to a defined range of tilt, or angle of operation of the transmitter pen 30.

It is preferable for most transmitter pen designs that the finger guard 38 be acoustically transparent, such that the transmitted output signal 24, which is typically an ultrasonic signal 24, is not reduced or redirected, due to reflection, refraction, or absorption of the output signal 24. Therefore, it is preferable that the design of the finger guard 38 minimize the effects on the radiated ultrasonic beam angles and sound pressure level (SPL) 86 of the output signal 24.

Figure 7 is a partial perspective view of a transmitter stylus 30b having a piezoelectric transducer 10 contained at the pointing tip 36b of the stylus 30b and surrounded by a finger guard 38. While the transmitter stylus 30b typically has similar construction to a transmitter pen 30a, the pointing tip 36b does not include ink from a writing pen 34, and is typically used in applications which do not require a visible written path 123 to be described within a writing area 104 (FIG. 25). In addition, a data entry transmitter stylus 30b,30d may have a smaller form factor (*e.g.* such as the diameter of the shell 32) than the form factor of a transmitter pen 30a,30b, since a data entry stylus 30b,30d does not typically include an internal writing pen 34. In some embodiments, the finger guard 38 resembles a honeycomb structure, with hollow sections that do not substantially disrupt the radial transmission path of the ultrasonic signal 24 towards all receivers 110 (FIGS. 23,25). In alternate embodiments, a substantially continuous lens

cover may be used. The lens cover can either be acoustically transparent, or can act to focus the transmitted signal towards the external receivers 110.

Figure 8 is a front view of a flexible circuit assembly 31 which is used in preferred embodiments of the transmitter pen 30a 30c (FIG. 10), 30e (FIG. 40) transmitter stylus 30b, 30d (FIG. 12), and eraser 200 (FIGS. 44,45). The signal input source 22 is located on the flexible circuit assembly 31, and is connected to lead connections 19a,19b by leads 18a,18b. The flexible circuit assembly 31 also includes a positive battery contact 33a, a negative battery contact 33b, and a switch contact 39. The relative order of battery contacts 33a, 33b and switch contact 39 may vary. Figure 9 is a partial cutaway view of a preferred transmitter pen 30, which includes the flexible circuit assembly 31. The piezofilm transmitter 10 is attached to the flexible circuit assembly 31 typically by eyelets, conductive adhesive, or heat stakes 19a,19b. Batteries 35 are located within the shell 32, and make contact with the positive battery contact 33a and the negative battery contact 33b. A switch 37, such as a pressure sensitive switch 37, is also located within the shell 32, and selectively makes contact with the switch contact 39, typically when the marking pen 34 makes contact with a writing surface 104 (FIGS. 23,25), thereby allowing the transmitter pen 30 to transmit an output signal 24 when the marking pen 34 makes contact with the writing surface 104.

Dual-Signal Transmitter Pen and Stylus. Figure 10 is a partial cutaway view of a dual-signal transmitter pen 30c having a first piezoelectric output signal transducer 10 and a second output signal transducer 44. While the dual-signal transmitter pen 30c is described as a pen, it can be any sort of movable transmitter device. The dual-signal transmitter pen 30c has multiple transducer elements 10,44 (FIGS. 10-13), which are used to determine the location of the pointing tip of the dual-signal transmitter pen 30c, in relation to a writing area 102, of a transmitter pen location system 100 (FIGS. 23, 25). The first output transducer 10 transmits a first output signal 24 from the dual-signal transmitter pen 30c, to first output signal sensors 111 at one or more of the external receivers 110 (FIGS. 23, 25). In one embodiment, the first output signal sensors 111 are ultrasound sensors, Part No. AT/R 40-10P, manufactured by Nippon Ceramic Co. Ltd., of Tottori-Shi, Japan. In this embodiment, the first output transducer 10 on the dual-signal transmitter pen 30c is an ultrasonic transmitter 10. In one

embodiment, the first output signal 24 pulse train has a periodic frequency of 50 pulses per second.

One or more second output elements 44, preferably electomagnetic or infrared transmitters 44, transmit a second output signal 48 from the dual-signal transmitter pen 30c to second output signal sensors 113 at one or more of the external receivers 110. In one embodiment, the second output signal sensors 113 are infrared photodiodes, Part No. SFH 205FA, manufactured by Siemens Microelectronics, Inc., of Cupertino, California.

The dual-signal transmitter circuitry 22b, connected to the first output signal transducer 10 through leads 18a and 18b, excites the first output signal transducer 10, to produce a first output signal 24. The transmitter circuitry 22b is also connected to the one or more second output signal transducers 44 through leads 42a and 42b, and excites the second output signal transducers 44, to produce a second output signal 48.

Figure 11 is a detailed cutaway view of the writing tip 36 of a dual-signal transmitter pen 30c having a first output signal transducer 10 and a second output signal transducer 44. Figure 12 is a partial perspective view of the pointing tip 36b of a transmitter stylus 30d having a single piezoelectric first output signal transducer 10 and a plurality of second output signal transducers 44. An optional finger guard 38 protects the first output signal transducer 10 and the second output signal transducers 44.

Output Signal Transmission. Figure 13 is schematic view 50 of the transmission of the combined output signal 50, which is comprised of a first output signal 10 and a second output signal 48.

The second output signal 48 is typically an infrared output signal 48, which is transmitted from one or more infrared transducers 44 located near the pointing tip 36 of the dual-signal transmitter pen 30c. Figure 14 shows a single short pulse waveform 56 of a typical second output signal 48 sent from a dual-signal transmitter pen 30c. In one embodiment, the infrared transducers 44 are Part No.

SFH426, manufactured by Siemens Microelectronics, Inc., of Cupertino, Califomia.

While only one infrared transducer 44 is required, the use of more than one infrared transducer 44 is preferred, since it allows better line-of-sight transmission of the second output signal 48 to each of the external receivers 18, such that the dual-signal transmitter pen 30c can be rotated by the user. In one embodiment of the dual-signal transmitter pen 30c, four infrared transducer 44 are radially located around the pointing tip 36 of the dual-signal transmitter pen 30c, each having a viewing angle of approximately 120 degrees, thereby providing an overlap of transmitted signals 48, such that the second output signal 48 is consistently received at receivers 110. As shown in Figure 11 and Figure 12, the second infrared transducers 44 are typically displaced from the centerline of the transmitter pen, by a distance of approximately three to four millimeters.

The first output signal 24 is typically an ultrasound output signal 24, which is transmitted from one or more ultrasound transducers 10 located near the pointing tip 36 of the dual-signal transmitter pen 30c. In one embodiment, the ultrasound transducer 10 is a cylindrical layered piezoelectric layer 12 surrounded by an outer conductive layer 16a and an inner conductive layer 16b, which is connected to the transmitter circuitry 22b by leads 18a and 18b and lead connections 19a and 19b. In another embodiment, the ultrasound transducer 10 used is Part No. AT/R 40-10P, manufactured by Nippon Ceramic Co. Ltd., of Tottori-Shi, Japan.

Figure 15 shows a first shaped pulse waveform 24a and a second, subsequent shaped pulse waveform 24b sent from a transmitter pen 30. While an ultrasound output signal 24 can have any waveform shape, including a single ultrasound pulse 62, it is preferred that the waveform be shaped to have a short duration, with distinctive wave characteristics, which allows the waveform to be measured and compared accurately, to provide an accurate calculated position for the transmitter pen 30 on a frequent basis. In the preferred embodiment shown in Figure 15, the subsequent first output signals 24a, 24b each include two major pulses 62a and 62b, with specific timing between them. The short duration output signals 24 allow the transmitter pen 30 to send sequential output signals more frequently. The use of the short duration ultrasound output signal 24 with

distinctive waveform characteristics 62a,62b also allows the transmission of other information to be sent from the transmitter pen 30 to the external receivers 110 (FIG. 23,25), as discussed below. While there are sometimes differences between the received amplitude of the subsequent first output signals 24a and 24b, each of the signals 24 retain major features, such as waveform characteristics 62a,62b, as well as wavelength dependent features, such as peaks 66a, 66b, 66c, and 66d. Comparison of these features between subsequent stored digitized output signals 24a and current output signals 24b allows the calculated transcribed path 82 of a transmitter pen 30 to be accurately determined.

Transducer Design Considerations. The sizing and relative geometry of the piezoelectric transducer 10 can effect the performance of the assembly. As well, a support spool 72a,72b (FIGS. 16,17) can be included, as discussed below, to improve the transmission performance of the output signal 24.

Transducer Height. The height dimension of the piezoelectric transducer 10, defined by the effective height of the electrode layer, defines the vertical beam angle 26 of the signal 24 transmitted from the piezoelectric transducer 10. When used in a transmitter pen 30a,30c or transmitter stylus 30b,30d, the vertical beam angle 26 of the pen 30 is determined by the height-to-diameter ratio of the transducer 10. Therefore, the average writing angle 106 of the transmitter pen 30, when operated by a user, is a design consideration when choosing an appropriate piezoelectric transducer 10 to successfully transmit an output signal 24 to remote receivers 110.

Transducer Diameter. For a specified beam angle and height dimension of the piezoelectric transducer 10, the diameter of the piezoelectric transducer 10 30 is typically minimized, to create an ergonomic form factor for the transmitter pen 30. The diameter of the piezoelectric transducer 10, generally defined by the diameter of the piezoelectric film 12, can affect the resonance frequency of the output signal 24 transmitted from the assembly. As the diameter or area of the transducer increases, the resonance frequency decreases. In this manner, the cylinder diameter of the piezoelectric transducer 10 can be chosen to contribute to the tuning of the transmitter pen design for a given receiver frequency.

Transducer Spool. Figure 16 is a partial crosssectional view 70a of an alternate embodiment of a piezoelectric transducer 10, which includes an inner spool 72a. The piezoelectric transducer shell 12 is loosely supported by the spool 72a. The spool is in contact with non-electroded areas of the piezoelectric transducer shell. When the piezoelectric transducer 12 shell is activated by the input signal 21, the spool 72a acts to maintain the shape and alignment of the transducer 10, without adversely affecting the sound pressure level 86 of the output signal 24. While the spool 72a can be a separate component located within the piezoelectric transducer shell 12, it can also be an integrated detail of a shell of a writing pen 34, when the piezoelectric transducer 10 is used within a transmitter pen 30. Lead connections 19a and 19b between the power source circuit 22a, 22b and the conductive outer layers 16a and 16b can be made either before or after the piezoelectric transducer 10 is placed onto the spool 72a.

In operation, the PVDF film 12 typically expands and contracts slightly, due to the piezoelectric effect of layer 12, from the input of electrical energy signal 21 to produce an output mechanical signal 24. Therefore, the piezoelectric transducer 10 should be loosely contained around the spool 72, thereby allowing the piezoelectric transducer 10 to resonate freely upon activation. There are also several techniques with which to affix or mount the piezoelectric film 12 to the spool 72, which also allow the piezoelectric transducer 10 to resonate freely when activated. The piezoelectric film 12 can be affixed to the spool 72 by either the bottom edge 73a of the film 12 and the spool 72, as shown in Figure 17, or by the top edge 73b of the film 12 and the spool 72.

In most embodiments, either the bottom edge 73a or the top edge 73b of the piezoelectric transducer 10 is kept free, which allows the piezoelectric transducer 10 to expand and contract, in reaction to thermal expansion and contraction, and in reaction to vibration from electrical excitation. Double-edged support can cause damage to the film 12 over wide temperature ranges unless the fit is loose.

Adhesive techniques may also be used to attach the piezoelectric film to the spool 72, such as with pressure-sensitive adhesives or light-curable manufacturing-grade adhesives, which can be applied to either or both surfaces, and then cured to quickly produce a permanent attachment.

Figure 17 is a partial crosssectional view 70b of an alternate embodiment of a piezoelectric transducer 10 and an inner spool 72b, in which a recess in the spool 72 creates an air cavity 76 defined between the inner diameter 77 of the spool 72b and the piezoelectric transducer 10. The thickness of the air cavity 76 may be designed to substantially increase the sound pressure level (SPL) output 86 produced by the energized piezoelectric transducer, as compared to a piezoelectric transducer 10 and a spool 72a without an air cavity 76. The depth 75 of the defined air cavity 76 is preferably greater than or equal to a predetermined defined minimum depth 75, to promote optimal sound pressure level output 86 performance. In one embodiment, the sound pressure level (SPL) output 86 is increased up to 100 percent, thereby providing enhanced control of the sound pressure level 86 and resonant frequency of the piezoelectric transducer 10. The formed air cavity 76 also allows the active area of the film 12 defined by the area of film 12 covered by electrodes 16a and 16b to avoid direct contact with the spool 72, since the piezoelectric film 12 on the piezoelectric transducer 10 can contact either the bottom edge 74a or the top edge 44b of the spool 42b. This assures that the active area of the film 12 can freely resonate. An another preferred embodiment, the spool 72 is fabricated as an integrated assembly component with an integral finger guard 38 (*e.g.* such as by a single injection molded part), which can reduce manufacturing tooling and assembly costs, and insure correct alignment of the transducer assembly.

Transducer Performance. Figure 18 is a graph 80a of the output sound pressure level 86a from a piezoelectric transducer 10, without an inner spool 72, which shows sound pressure level 82 as a function of output frequency 84 for the output signal 24. Figure 19 is a graph 80b of the output sound pressure level 86b from a similar piezoelectric transducer 10 with an inner spool 72.

Formed Piezoelectric Transducer Assembly. While the piezoelectric transducer 10 can be formed from a continuous piezoelectric shell 12, the piezoelectric transducer 10 can alternately be formed by other methods. Figure 20 is a front view of a flat, flexible piezoelectric film assembly 90 having opposing conductive layers 16a, 16b and lead attachment extension tabs 92a and 92b. Figure 21 is a side view of a flat piezoelectric assembly 90 having

opposing conductive layers 16a and 16b and lead attachment extension tabs 92a and 92b. The flat piezoelectric assembly 90, currently available as a commercial or custom component from Measurement Specialties, Inc. of Fairfield, New Jersey or Ktech Corp., of Albuquerque, New Mexico, is formed into a shell structure, which is used as a piezoelectric transducer 10b. Part No. DT-40 from Measurement Specialties, Inc. is a suitable commercial component. Outer layers 93a and 93b provide protection for conductive layers 16a and 16b and conductive tabs 94a and 94b, respectively.

The lead attachment extension tabs 92a and 92b serve to simplify the manufacturing process of a transducer 10 that is suitable for use in a data entry pen 30a,30c, data entry stylus 30b,30d, or data entry eraser 200a,200b (FIGS. 44,45). PVDF film 12 is easy to cut and form. Electrode extension 94a is an extension of conductive layer 16a that extends onto extension tab 92a. Similarly, electrode extension 94b is an extension of conductive layer 16b that extends onto extension tab 92b. Signal leads 18a and 18b are connected to electrode extensions 94a and 94b. In an alternate embodiment, connector holes 96a and 96b provide a mechanical means for connecting signal leads 18a and 18b to electrode extensions 94a and 94b, respectively.

Figure 22 is a perspective view of a piezoelectric transducer shell 10b formed from a flat piezoelectric assembly 90. In most embodiments, the piezoelectric film 90 is first rolled into and confined within a generally cylindrical shape, commonly with a small overlapping region 79. The overlapping region 79 is typically connected by adhesive, heat stake, or ultrasonic bonding techniques. The rolled piezoelectric transducer 10 is then preferably placed onto a spool 72. The piezoelectric transducer 10 is loosely contained by the spool 72, and is attached to the flex circuit, as shown in Figure 8 at points 19a and 19b, typically by electrically conductive eyeletting or riveting, to leads 18a,18b on flexible circuitry 31. It is preferable that the attachment method used reduces the manufacturing cost and improves the yield and manufacturability of the transducer assembly.

Production of Formed Piezoelectric Transducer Production Process. The formed piezoelectric transducer 10b production process comprises the following steps:

i) forming conductive layers 16a and 16b on opposing sides of a piezoelectric film layer 12 having a bottom edge 73a, a top edge 73b, a first side edge 75a, and a second side edge 75b;

ii) rolling the piezoelectric film layer 10 into a shell having a hollow region 77 defined therein, wherein the first side edge 75a and second side edge 75b overlap to form an overlapping region 79; and

iii) forming a connection 98 between the first side edge 75a and second side edge 75b within the overlapping region 79.

The process may also include an additional step of connecting signal leads 18a and 18b to the conductive layers 16a and 16b. Additionally, the process may also include a step of containing a spool 72 having a bottom edge 74a and a top edge 74b within the hollow region 77, and preferably aligning either the bottom edge 74a of the spool 72 to the bottom edge 73a of the piezoelectric film layer 12, or attaching the top edge 74b of the spool 72 to the top edge 73b of the piezoelectric film layer 12.

Data Entry Systems. Figure 23 is a perspective view of data entry system 100, in which a piezoelectric transmitter pen 30 is shown at an inclined angle 76 in relation to a writing surface 102, wherein the inclined angle is indicated as θ. The writing surface 102, such as a white board or writing tablet, typically has a data entry area 104 (*i.e.* a writing area), which includes an X coordinate axis 114, and a Y coordinate axis 116. Output signals 24 from the piezoelectric transmitter pen 30a,30c are output from the piezoelectric transducer 10, and are received by sensors 111 located at one or more receivers 110. The output signals 24 are then processed in the receiver modules 110, or are transferred to an external signal processor 120, such as through a cable 112. The output signals 24 can be used to transmit information to the remote receivers, such as the location of the pointing tip 36 of the pen 30a,30c in relation the data entry area 104, or other

appropriate information, as desired. The output signals 24 may consist of only ultrasound signals 24, or may also be any combination of ultrasound, infrared, and optical signals. As seen in Figure 13, a dual-signal transmitter pen 30c may be used to transmit a combined signal 50 to the external receivers 110, comprising both a first output signal 24 (*e.g.* such as an ultrasound signal 24) and a second output signal 48 (*e.g.* such as an infrared signal 48).

Figure 24 is a partial detailed side view which shows the relative geometry between a piezoelectric transmitter pen 30 and a writing surface 102. Point P_0 (124) corresponds to the location of the pointing tip 36 of the pen 30 on the writing surface 102. Point P_1 (126) corresponds to the projected location of the piezoelectric transducer 10 of the transmitter pen 30 onto the writing surface 102. Figure 25 is a front view of a piezoelectric data entry device, such as a transmitter pen 30, being used against the writing surface 104 of a wall-mounted white board 102, and illustrates the calculated path of the data entry device 30, 130 (FIG. 26), 200a,200b (FIG. 44,45) against the writing surface 102, traveling from a first point 121a having coordinates (X_1,Y_1) along a path 123, through a second calculated point 121b having coordinates (X_2,Y_2), and ending at a third point 121c having coordinates (X_3,Y_3).

Alternate Transducer Embodiments. Figure 26 is a top view of a piezoelectric transmitter mouse 130, wherein a piezoelectric transducer 10 is placed within a portable mouse housing 132. In a similar manner to the transmitter pen 30a,30c, the piezoelectric transmitter mouse 130 is used as a data entry device to send one or more output signals to remote receivers 80. A transducer guard 134 is preferably placed over the piezoelectric transducer 10. In a similar manner to the transmitter pen embodiment finger guard 138, it is preferable for most transmitter mouse designs that the transducer guard 134 be acoustically transparent, such that the transmitted output signal 24, which is typically an ultrasonic signal 24, is not reduced or redirected, due to reflection, refraction, or absorption of the output signal 24. Therefore, it is preferable that the design of the transducer guard 134 reduce the effects on the radiated ultrasonic beam angles and sound pressure level (SPL) 86 of the output signal 24.

Figure 27 is a cross-sectional view of a multiple element cylindrical transducer 10c, whereby a pattern of opposing electrode pairs 16a,16b are located on the outer and inner surfaces of a piezoelectric cylinder 12. The essentially cylindrical transducer 10c is formed by applying a pattern of discontinuous electrodes 16a,16b to a piezoelectric layer 12. Figure 28 is a side view of a multiple element transducer 10d formed by a discontinuous electrode pattern, whereby alternating layers of piezoelectric material 12 and electrode layers 16 are formed together.

Figure 29 is a cross-sectional view of a composite 138a of piezoelectric material segments 142 within an insulative substrate 144. The composite 138a is either initially formed as a planar substrate, and then processed into a transducer shell, as discussed above, or is directly formed into a shell structure. Figure 30 is a cross-sectional view of a segmented piezoelectric transducer 10e, whereby piezoelectric segments 142 are selectively powered, either together or separately, to produce an output signal 24. The piezoelectric segments 142 are typically constructed from ceramics, such as lead zirconium titanate (PZT), lithium niobate (LiNb), or lead metaniobate (PbNb) materials. The substrate 144, typically a polymer, has a Young's modules that is much lower than the piezoelectric material.

Figure 31 is a cross-sectional view of a composite 146a of segmented piezoelectric material 142 within a conductive substrate 144. The conductive substrate 144 can be connected to first power lead 18a, while the upper electrodes of the piezoelectric segments 142 are connected, either together or separately, to a second power lead 18b.

In alternate embodiments, piezoelectric elements 142 are mounted to one surface of insulative substrates 144 or conductive substrates 148. Figure 32 is a cross-sectional view of a composite 138b of segmented piezoelectric transducer elements 142 located on an insulative planar substrate 144. Figure 33 is a cross-sectional view a surface-mounted segmented piezoelectric transducer 10f, in which segmented piezoelectric transducer elements 142 are located on an insulative cylindrical substrate 144. Figure 34 is a cross-sectional view of a

composite 146b of segmented piezoelectric transducer elements 142 located on a conductive planar substrate 148.

Figure 35 is a partial cutaway view of a composite structure 150a comprising separated piezoelectric segments 142, which are separated by an intermediate material 152. The composite 150 is formed, either as a continuous material, or is directly formed into a shell structure. Figure 36 is a partial cutaway view of an alternate composite structure 150b comprising separated piezoelectric segments 142, which are separated by an intermediate material 152. Electrodes 16a and 16b located on opposing surfaces of the piezoelectric segments 142 are bonded to electrical leads 18a and 18b. Bonding may be accomplished by electrically conductive epoxy, solder, or other means of maintaining contact between electrodes 16a,16b and electrical leads 18a,18b. Figure 37 is a cross-sectional view of a composite segmented piezoelectric transducer 10g, whereby piezoelectric segments 142 are selectively powered, either together or separately, to produce an output signal 24. The composite structure 150 is typically formed from ceramic piezoelectric segments 142 and polymer segments 152.

Continuous Thick-Walled Piezoelectric Transducer. Figure 38 shows an alternate shell piezoelectric transducer 10h, formed from a continuous thick-walled tube of PVDF piezoelectric material (*e.g.* commonly about 1 millimeter in thickness). Figure 39 shows a poling process 158 for during the production of an extruded thick-walled tube 10h of PVDF piezoelectric material 142, wherein an inner electrode 160 is placed longitudinally within the internal cavity 156 of the tubing 10h, and an outer electrode 162 is placed around the outer circumference of the piezoelectric tubing 10h. The piezoelectric tubing 10h is subjected to an elevated processing temperature within a processing chamber 164, while an electric field is applied by a power source 166 between the inner electrode 160 and the outer electrode 162, whereby the piezoelectric tubing 10h is magnetically poled, thus producing the piezoelectric properties for the continuous tubing 10h. The entire surface area on the inside of the cylindrical piezoelectric tubing 10h becomes one electrode 161, while the entire surface area on the outside of the cylindrical piezoelectric tubing 10h becomes an opposing electrode 163.

Continuous logitudinally poled shell piezoelectric transducers 10h are currently available from Amp, Incorporated. However, the current cost to produce continuous logitudinally poled shell piezoelectric transducers 10h is relatively high, as compared to the cost to produce a rolled piezoelectric transducer 10b, or even as compared to the cost of using multiple ceramic transducers 142.

The density (*i.e.* the formulation) and the thickness of the cylindrical piezoelectric tubing 10h are preferably chosen such that the cylindrical tubing 10h provides resonation at a desired frequency, while the cylindrical tubing 10h remains structurally stable (*i.e.* to retain its shape).

Preferred Transmitter Pen Embodiments. Figure 40 is a partial side view of a preferred embodiment of a transmitter pen 30e, which includes two opposing (*i.e.* clam-shell) connectable housing halves 32a, 32b. Figure 41 is a partial end assembly view of the preferred embodiment of a transmitter pen 30e shown in Figure 40. Each of the halves 32a,32b define opposing hollow pen regions 170a and 170b, as well as hollow circuitry regions 172a and 172b, such that when the clamshell halves 32a, 32b are joined to each other, a flex circuit cavity 174 is defined (thus containing and protecting the circuitry 31), and a writing pen cavity 176 is defined, from a rear access end 178 to a front writing end 180 of the clamshell pen 30e. A writing pen 34, such as a whiteboard felt tipped pen 34, may then be slidably placed into the writing pen cavity 176, whereby the felt tip 36 of the writing pen 34 extends through the writing tip end 176 of the clamshell body 32a, 32b. An endcap 182 is then fixedly closed to the rear end of the clamshell body 32, thereby retaining the writing pen 32 within the clamshell body 32, so that the user may write on a writing surface 104, while the signal transducers 10,44 send signals to the external receivers 110.

The rear endcap 182 preferably contains a battery compartment 186 and a battery compartment closure 188. The rear end cap 182 also preferably includes a hinge attachment 184, by which the end cap 182 may be hingedly opened and closed.

The flexible circuitry 31 is located within the circuitry cavity 174 which is formed between the clamshell halves 32a and 32b, thereby protecting the internal electronic componentry 22. Flexible electrical connections 33a,33b (FIG. 8) are also preferably located between the battery compartment 186 and the flex circuit 31. When the rear cap 182 is opened, the cylindrical pen cavity 176 is accessible, whereby a user my install or replace a writing pen 34.

The transmitter pen 30e preferably includes a color identifier 190, which allows a user to quickly identify the designated color for a marking implement. As well, the transmitter pen 30e preferably includes encoded color information within the transmitted signals from either the piezoelectric output transducer 10 or from second output transducers 44. For transmitter pens 30e which include encoded color information, the color identifier 190 typically matches the encoded color of the pen (*e.g.* such as black, red, blue, or green). For embodiments wherein the finger guard 38 includes an identifying color 190, which matches the encoded color of the transmitter pen 30e, the finger guard 38 is preferably fixedly attached (*e.g.* such as by gluing or heat staking) to the pen housing 32, such that the identifying color 190 of the finger guard 38 matches the encoded color of the pen 30e.

Most embodiments of the transmitter pen 30 provide a single encoded color identifier within the pulse train of either the first output signal 24 or the second output signal 48. As well, the piezoelectric transmitter pen 30 preferably accepts standard whiteboard marking pens 34 to be installed within the marking pen cavity 176. Since standard whiteboard marking pens 34 having different colors typically have a similar form factor, a writing pen 34 having any color of ink (*e.g.* blue, green, black or red) may be installed within the marking pen cavity 176 of a piezoelectric transmitter pen 30. It is therefore desirable that a user install an appropriate marking pen having a color of ink which matches the designated color (*i.e.* the encoded color) of the piezoelectric transmitter pen 30.

Ceramic Piezoelectric Transmitters for Data Entry Devices. In alternate embodiments of the piezoelectric transducer 10, ceramic material, such as lead zirconium titanate (PZT), lithium niobate (LiNb), or lead metaniobate (PbNb) materials, may be used, wherein opposing surfaces of ceramic material 142

(FIGS. 29-37) are poled, at an elevated temperature, to produce piezoelectric properties between the opposing surfaces of the ceramic material 142.

Figure 42 shows an end view 190 of an alternate embodiment of a dual-signal data entry device 191a (*e.g.* such as an electronic marking implement 30 or erasing implement 200), having a plurality of infrared transmitters 44, as well as a plurality of piezoelectric ceramic transmitters 142. Figure 43 shows an end view 194 of an alternate embodiment of a single-signal data entry device 191b (*e.g.* such as an electronic marking implement 30 or erasing implement 200), having a plurality of piezoelectric ceramic transmitters 142. Each of the piezoelectric ceramic transmitters 142 is typically comprised of a block of piezoelectric ceramic material, wherein opposing surfaces are poled (*e.g.* positive polling on a first surface , and negative polling on an opposing second surface). Each of the piezoelectric ceramic transmitters 142 are then typically placed symmetrically about a transmitter mounting surface on the data entry device 191 (*e.g.* such as around the writing end 178 of a transmitter pen 30), whereby respective poled surfaces (*e.g.* each of the positively poled surfaces) are aligned radially outward from the axis of the data entry device 191. Since the piezoelectric ceramic transmitters 142 each produce a directional output signal 24, a plurality of piezoelectric ceramic transmitters 142 are placed around the data entry device 191.

Each of the piezoelectric ceramic transmitters 142 are preferably mounted to electrically conductive signal traces 179a and 179b, wherein the first outwardly opposing faces of the piezoelectric ceramic transmitters 142 are connected to a first signal trace 179a, and wherein the second inwardly opposing faces of the piezoelectric ceramic transmitters 142 are connected to a second signal trace 179b.

The resulting output signals 24 from the plurality of piezoelectric ceramic transmitters 142 are typically of greater magnitude than an output signal 24 from a rolled piezoelectric film transmitter 10b. Therefore, the piezoelectric ceramic transmitters 142 may be relatively small in size, thereby permitting a variety of pen housing designs 32. As well, the increased signal strength for a plurality of

piezoelectric ceramic transmitters 142 allows a piezoelectric data entry device to be used for large writing areas 104.

Since piezoelectric ceramic transmitters 142 are comprised of ceramic materials, they provide structural stability, and typically do no require the use of a spool 72. However, preferred data entry devices 30, 200 which include piezoelectric ceramic transmitters 142 typically include a protective guard 38, to prevent damage to the transmitters 142.

Piezoelectric Erasing Implements. Figure 44 is a partial cross-sectional view of a single-signal erasing implement 200a. Figure 45 is a partial cross-sectional view of a dual-signal erasing implement 200b. The first output transducer 10 used for the erasing implement 200 is similar in construction to a piezoelectric transducer 10 used for a marking implement (*e.g.* such as for a transmitter pen 30). As well, for embodiments which include a rolled film piezoelectric transducer 10b, the rolled transducer 10b is mounted in a similar manner, wherein the rolled film piezoelectric transducer 10b is typically loosely press fit over a backing spool 72, which preferably includes an air cavity 76 (FIG. 17).

The eraser assembly 200a, 200b includes an erasing pad 202 mounted to a lower housing 204. An upper eraser housing 206, preferably having an ergonomic contour by which the erasing implement 200a, 200b may be held by the user, is preferably hollow, defining an inner cavity 208, wherein the erasing implement flex circuitry 210 is contained. The upper housing 206 also includes a battery storage compartment 212, wherein one or more batteries 35 (*e.g.* such as coin cell batteries 35) are placed to power the erasing implement 200. Power connections 211a,211b, which make electrical connections between the batteries 35 and the driver circuitry 22 (FIG. 8), are preferably integral to the flex circuitry 210.

In most embodiments, the rolled film piezoelectric transducer 10b is preferably held in place by an eraser finger guard 222, which helps to retain the round cross-section of the rolled film piezoelectric transducer 10b, and protects the rolled film piezoelectric transducer 10b from direct physical contact by a user. In alternate embodiments of the eraser assembly 200a, 200b having multiple piezoelectric

first output ceramic transducers 142, an eraser finger guard 222 is also preferred, since the eraser finger guard 222 prevents damage to the ceramic material 142, which may be brittle.

Figure 46 is a top view of a defined path 230 of a piezoelectric erasing implement 200 on a white board system 100. When the erasing implement 200 is placed upon a writing surface 104, the first output transducer 10 (*e.g.* such as a rolled film piezoelectric transducer 10b) is powered by the eraser flex circuitry 210, and emits an ultrasonic erasing signal 224, which is received at receivers 110.

The received signal 224 is repeatedly processed by a signal processor 120 (FIG. 23), to determine the current location 221 of the erasing implement 200, such as along a calculated erasing path 230, traveling from a first point 221a having coordinates (X_4,Y_4) along erasing path 230, through a second calculated point 221b having coordinates (X_5,Y_5), and ending at a third point 221c having coordinates (X_6,Y_6).

The erasing signal 224 preferably includes an effective erasing area signal 218 included within the pulse train 224, by which the signal processor 120 calculates an area (*e.g.* an effective diameter or swath 220) for the erasing implement 200, which is preferably similar (*i.e.* coaxial) to the current location of the erasing pad 202. The calculated swath 220 of the erasing implement 200 is therefore preferably matched to the actual swath of the erasing pad 202, such that the calculated images defined on a writing surface 104 correspond to the visible path of the writing pens 32 within the marking implements 30 upon the writing surface 104.

While the calculated path 230 of a piezoelectric erasing implement 200 on a white board system 100 may be defined by successive straight-line segments between sequential locations 221 of the erasing implement 200, the calculated path 230 may alternately include curve approximation within the signal processor 120.

In a single-signal piezoelectric erasing implement 200a, the erasing signal 224 typically includes encoding which indicates the erasing function of the implement 200a, such that it can be used in conjunction with one or more transmitter pens 30. In a dual-signal piezoelectric erasing implement 200b, either the erasing signal 224 or the second output signal 248 includes encoding which indicates the erasing function of the implement 200a, such that it can be used in conjunction with one or more transmitter pens 30.

A plurality of erasing implements 200a and 200b are preferably used for a white board system 100, whereby a user may erase varying sized paths 230 (*i.e.* varying diameters 220) on a whiteboard surface 104, such as both by erasing actual writing paths with the erasing pad 202 on the piezoelectric erasing implement 200a, 200b, while sending an erasing signal 224 which defines a transmitted erasing path, thereby "erasing" previously transmitted and stored marking paths 123.

Therefore, a user may preferably use a plurality of erasing implements 200 having a variety of effective erasing areas 220 (*e.g.* such as having a first erasing implement 200 having a one inch effective erasing area diameter 220, and a second erasing implement 200 having a four inch effective erasing area diameter 220). For example, a user may prefer to use a small diameter erasing implement 200, having a small erasing pad 202 and a matching encoded erasing area 220, to erase small areas of a white board (*e.g.* such as to edit a detailed drawing on the white board). In addition, the user may prefer to use a large diameter erasing implement 200, having a large erasing pad 202 and a matching encoded erasing area 220, to erase large areas of a white board 104 (*e.g.* such as to erase large regions of a white board quickly and completely).

For a piezoelectric erasing implement 200 which includes a single piezoelectric transmitter 10, or for embodiments which use a plurality of piezoelectric transmitters (*e.g.* such as piezoelectric ceramic transducers 142) which act as a single point source 221a-221n, the signal processor 120 produces a circular erasing pattern 220, having a specified radius, which extends from the calculated locations 221a-221n of the piezoelectric transmitter 10.

In alternate embodiments, for a piezoelectric erasing implement 200 having more than one piezoelectric transmitter 10,142, wherein each transmitter emits a unique location signal 224, the relative location of the erasing implement 200, as well as the orientation (*i.e.* the rotation of the erasing implement 200) may be determined. For example, for an erasing implement 200 having an erasing pad 202 with a rectangular shape (similar to a conventional white board eraser), an erasing implement 200 having two or more piezoelectric transmitters may preferably be used to define an encoded rectangular periphery, using the calculated location of each of the transmitters 10, 142 to determine the effective orientation of the erasing implement 200 in relation to a writing surface 104.

Combined Marking and Erasing Implement. Figure 47 shows a preferred embodiment of a combined piezoelectric marking and erasing implement 230, having the writing tip 36 of a writing pen 34 (whereby a user may define a writing path 123) on a first writing end 180, as well as an erasing pad 202 and calculated erasing path 230 on an opposite erasing end 232.

The power storage batteries 35 and power circuitry may be used for both marking and erasing functions. The marking circuitry 22 and marking transmitter 10, including the encoded pen size and color contained within the signal pulse train 24, is typically powered when the writing end 180 is in contact with the writing surface 104. The erasing circuitry 211 and erasing transmitter 10x, including the encoded eraser diameter 220 contained within the signal pulse train 224, is typically powered when the erasing end 232 is in contact with the writing surface 104. In some embodiments, wherein both marking transducer 10 and erasing transducer 10x are powered when the pen is used, the system processor 120 only accepts incoming data (*e.g.* either writing signal 24 or an erasing signal 224) for the end of the combined writing implement 230 which is currently in contact with the writing surface 104.

The combined marking and erasing implement 230 provides a useful tool for many users, in which a user may quickly edit (*i.e.* erase) small areas within the writing area 104 of a writing board 102, in a manner similar to a conventional eraser located on a conventional pencil. The size of the erasing pad 202 (and the calculated erasing path 230) on the erasing end 232 of a combined marking and

erasing implement 230 is preferably matched to approximate the size of the writing pen 34 (and defined writing path 123) on the writing end 180 of a combined marking and erasing implement 230 (similar to a conventional eraser on a conventional writing implement).

While a user would typically use the erasing end 232 on the combined marking and erasing implement 230 to erase small areas on a writing area 104 (*e.g.* such as to correct mistakes), the user would typically use a dedicated erasing implement 200 to erase large areas (*e.g.* such as to erase a large portion of the writing surface 104).

Although the piezoelectric transducer and its methods of use are described herein in connection with data entry and computer input pointing, marking and erasing systems, the techniques can be implemented for other instrumentation control or display devices, or any combination thereof, as desired.

Accordingly, although the invention has been described in detail with reference to a particular preferred embodiment, persons possessing ordinary skill in the art to which this invention pertains will appreciate that various modifications and enhancements may be made without departing from the spirit and scope of the claims that follow.